2.9 THE CLIMATE OF THE GREENLAND ICE SHEET AS SIMULATED BY POLAR MM5

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1. INTRODUCTION

Because Greenland's radiative characteristics and boundary layer dynamics resemble those of Antarctica (Schwerdtfeger 1972), similar surface wind features were observed by early expeditions (Manley 1938), and are found on modern satellite imagery (Rasmussen 1989, Bromwich 1989, Heinemann and Klein 2002). The strong cooling of the air adjacent to the slope ice sheet results in a horizontal pressure gradient force directed downslope. Mass transport associated with the katabatic wind regime may play a crucial role in regional climate (Bromwich et al. 1996). The katabatic wind may influence the development of cyclones over the coastal waters of Greenland (Carrasco and Bromwich 1994, Rasmussen et al. 1997).

Greenland is one of the least studied areas in the Northern Hemisphere from a meteorological perspective (Rasmussen et al. 1997). The Greenland climate has not been explored thoroughly due to the shortage of observations over the ice sheet. Since 1995, 20 automatic weather stations (AWS) have been established on the ice sheet (Swiss Camp was installed in 1990) (Steffen and Box 2001) to complement the unevenly scattered manned sites, whose observations were short and/or discontinuous and were concentrated in the southern half of Greenland. In this study, Polar MM5 (Bromwich et al. 2001, Cassano et al. 2001) is used to simulate the climate over the Greenland Ice Sheet.

2. DATA AND METHODS

Six extended winter season simulations from September to the next March of 1985-1986, 1992-1993, 1995-1996, 1997-1998, 1998-1999, and 1999-2000 over Greenland by Polar MM5 with a single domain are run to describe the ice sheet climatology. These six extended winter seasons are selected such that three of them represent extreme negative NAO winters and the other three represent extreme positive NAO winters. The domain has 40km spacing covering Greenland and its vicinity. In the vertical, there are 28 sigma levels. The initial fields and boundary conditions are interpolated from ECMWF TOGA archived data. Each model run consists of 11 days continuous integration with nudging toward TOGA gridded analyses, with the first 24 hours being discarded for model spin-up reasons. Therefore the remaining 10 days of model output are used for analysis.

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3. RESULTS

Figure 1 shows the 6-year-average total 7-month precipitation from Polar MM5 simulations. Generally, the 7 month total precipitation pattern is very similar to the annual mean precipitation obtained by Chen et al. (1997). The largest precipitation occurs in the southern part of Greenland. More precipitation is simulated along the coast than in the interior. Along the western side of Greenland, the southwestern coast has more precipitation than the northwestern coast. From the middle of the western coast to the interior between the two peaks of the Greenland Ice Sheet, a large amount of precipitation is simulated by Polar MM5, which is reviewed by Csatho et al. (1997). From the interior of Greenland (near Summit) to the northern coast, the precipitation is very small (less than 10cm for 7 months). The large coastal precipitation is due to the cyclone activity in adjacent regions. The precipitation over Iceland is a maximum over the southeast, and gradually decreases toward the northern part of the island. The northwest coastal precipitation center in Greenland is related to the cyclone activity over polynyas. For different seasons, the precipitation pattern shows different characteristics (not shown). In autumn, there is more precipitation along the western coast than that in winter, especially in the middle and northwestern coast, indicating more cyclone activity along the west coast in autumn compared to the winter season. The autumn precipitation over the southern tip of Greenland is larger than that in winter. Along the southeast coast, the model simulations show more precipitation in winter than in autumn.

The cyclone activity near Greenland is closely related to the North Atlantic Oscillation (NAO). The precipitation relationship with the NAO has shown that southern Greenland precipitation is negatively correlated to the NAO index (Chen et al. 1997). In a positive NAO year precipitation over southern Greenland is less than average, whereas in negative NAO years the southern Greenland precipitation is larger than average. The differences between average precipitation for positive and negative NAO seasons (7 months from September to March) show that the precipitation pattern can be divided into western Greenland precipitation and eastern Greenland precipitation (Fig. 2). The dividing line (zero contour line) is from the middle of northern Greenland, crossing Summit, to the middle of the southeast coast. In western Greenland, including the southern area, there is a large precipitation deficit. The deficit is from 33cm in northwest Greenland to 82cm in the southern tip of Greenland. Thus the precipitation deficit decreases from south to north. In eastern Greenland, precipitation increases when the NAO is positive. The maximum precipitation gain (41cm) is located near Scoresby Sund.

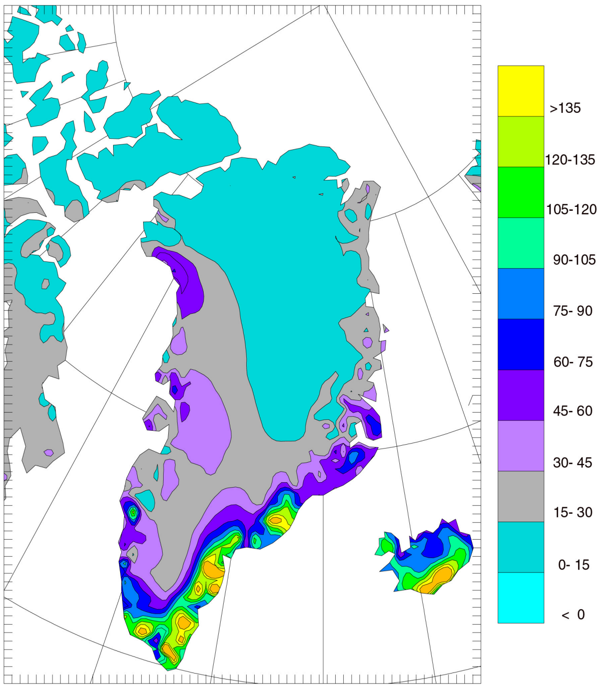

Figure 1 Polar MM5 simulated total mean precipitation for extended winter from September to March. Unit is cm.

Figure 3 shows the average monthly 2m surface air temperature for the extended winter season. We can see that there is a cold core (-39^oC) over the summit of Greenland Ice Sheet. The 2m surface temperature then increases toward the coast, with a symmetric pattern on the western and eastern sides. The 2m surface temperature is around -4^oC to -8^oC on the southern coast, -16^oC on the middle coast, and -20^oC to -24^oC on the northern coast. From south to north, the Greenland Ice Sheet spans 22 degrees latitude, thus the average 2m surface temperature gradient is from -0.9^oC/degree to -0.7^oC/degree latitude from September to March. The zero degree surface isotherm over the ocean (not the sea surface temperature) follows the southeast coast of Greenland with a southwest to northeast orientation.

From the average 10m surface wind vectors from Polar MM5 (not shown), it is noticeable that the downslope wind develops a clockwise circulation because of the Coriolis effect. The average surface wind on both west coast and east coast is northerly associated with low pressure troughs, therefore along the west coast, strong wind shear is found, while along the east coast downslope winds gradually merge into the environmental circulation. Over Denmark Strait, anticlockwise circulation represents the Icelandic Low.

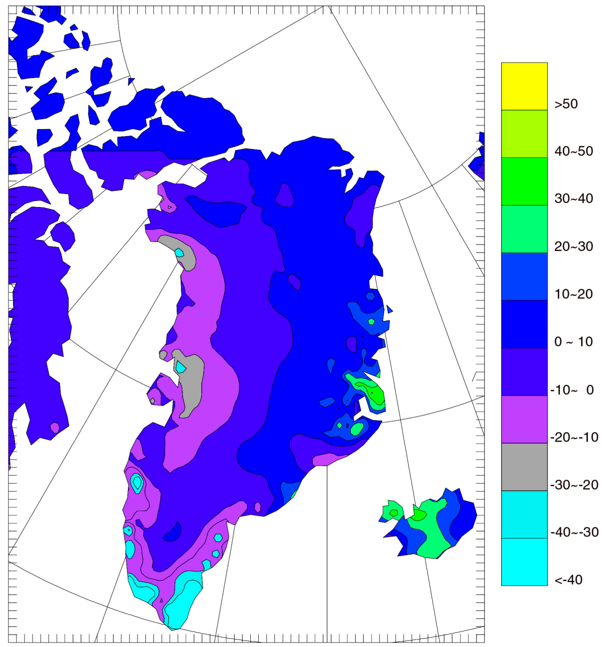

Figure 2 The difference between positive NAO months and negative NAO months. Unit is cm.

Although monthly surface wind over Greenland Ice Sheet does not show significant changes for the extended winter season, the surface wind for positive and negative NAO seasons shows much more significant variations (not shown). During positive NAO seasons, the surface wind is weaker than during the negative NAO seasons over most of the ice sheet. Over east of Greenland and along southeastern coast, stronger northerly winds occur during positive NAO months as the Icelandic Low shifts northeast. The clockwise katabatic wind has the same direction as the near ice sheet cyclonic wind direction, therefore when a cyclone approaches the eastern and southeastern coasts of Greenland, the near ice sheet cyclonic wind component accelerates the katabatic wind.

Because of the radiational cooling over the Greenland Ice Sheet, a near-surface temperature inversion is common, particularly during cloudless winter periods. The warmest temperatures on two adjacent model levels starting from the model bottom determines the inversion top. Then the temperature inversion strength is calculated by subtracting model lowest level temperature from the temperature at the model inversion top and the inversion height is the difference between inversion top height and model lowest level height. The largest temperature inversions (11^oC) for extended winter season (Fig. 4) are found in the northeast part of Greenland, where clear skies occur frequently and the midtropospheric westerly winds subside crossing the ice sheet, and gradually decrease toward the coastal boundaries. The near summit inversion strength is between 8^oC and 10^oC. The southern Greenland temperature inversion is around 4^oC.

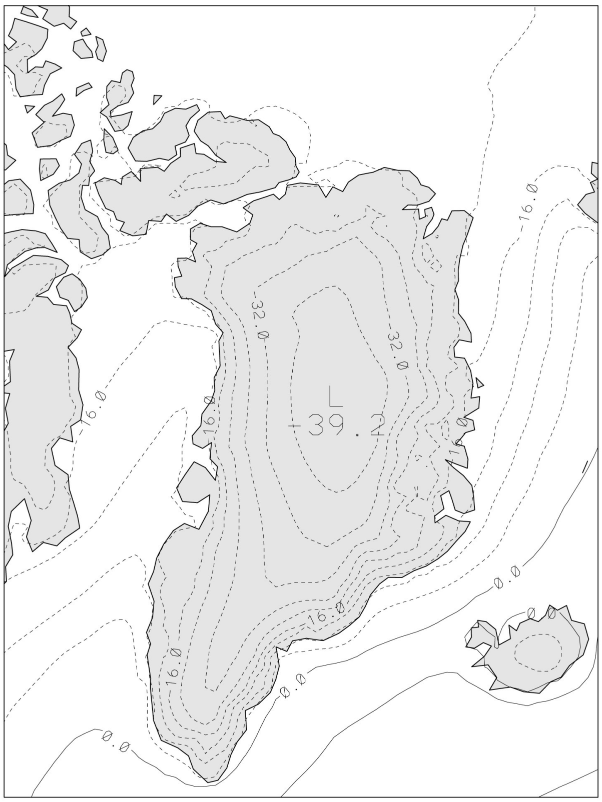

Figure 3 Mean surface temperature simulated by Polar MM5 for the extended winter season. The contour interval is 4^oC.

The spatial pattern of inversion depth differs from that of the temperature inversion strength. The average monthly inversion height for September to March indicates that there are two large inversion height areas (not shown). One is near the summit of the Ice Sheet, and the other is in north Greenland. The near summit inversion height maximum is around 400m for most months, reaching over 500m in winter. The northern inversion height center is more than 500m, with some inversions reaching 1000m near the northeast coast. Putnins (1970) pointed that the typical winter temperature inversion at Station Centrale (71^oN, 2993m) is 10^oC in the lowest 400m, which is similar to the results from the Polar MM5 model output. One noticeable phenomenon is that in the cold season, the temperature inversion height is very high near the coast. This may be associated with the adiabatic heating due to the katabatic flow from the inland Ice Sheet toward the Greenland coast region.

Figure 4 Model predicted mean surface temperature inversion (^oC) for the extended winter season. Contour interval is 2.

4. DISCUSSION

The climatology shown here from Polar MM5 describes the overall surface features over the Greenland Ice Sheet, which may be difficult to establish by using the short period automatic weather station (AWS) observations. The model performance has been established by comparing AWS 3-hourly observations with the model output. The correlation of surface pressure, temperature and relative humidity between model output and AWS observation are above 0.9. The average bias for surface temperature is less $-1^\circ C$. The surface pressure bias is within +/-3hPa. The correlation of wind speed between model output and observation is only 0.63, (however the correlation of wind direction is 0.9). The low correlation of wind field is attributable to two factors: model resolution is not high enough to capture the terrain variation to reproduce the local wind characteristics; and cold weather causes instrumental failure due to freezing.

The precipitation is the major source for ice sheet accumulation (other processes contributing to the ice sheet accumulation are drifting snow and evaporation). The precipitation pattern has a large difference between positive and negative NAO cold seasons. The surface wind has little difference for different NAO phases. On the temperature fields, positive NAO seasons have colder surface temperature than negative NAO seasons. Hanna and Cappelen (2003) indicate that the southern coast of Greenland experienced colder conditions, in contrast to the global warming during recent 44 years; this is consistent to the results in this study, because during the last 50 years, NAO has an upward trend. The results in the study further show that during positive NAO seasons, colder surface temperatures occur over the entire Greenland Ice Sheet, Baffin Bay, Labrador Sea and Denmark Strait, with coldest center in southeastern Greenland. The modeled temperature inversion is up to $10^{\circ}C$ and 400m deep over central Greenland. Although the verification of the near surface inversion has not been carried out yet, it should be realistic based on the verification of predicted surface variables by AWS observations.

5. ACKNOWLEDGMENTS

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